A. NOMENCLATURE

a	one cross-sectional dimension of a rectangular duct
A_i	area of pipe for orifice or venturi, measured at inner edge
A_j	area of jet, fully expanded
A_o	area of pipe for orifice or venturi, measured at outer edge
A_s	area of inlet debris screen
b	one cross-sectional dimension of a rectangular duct
B	number of blades, rotors or cylinders
BFI	Blade Frequency Index
ΔBN	differential ISO band number
c	sonic velocity
c_a	sonic velocity, ambient
c_e	sonic velocity, expanded gas
c_j	sonic velocity in jet
C	stator chord
C_1	inlet guide vane chord length
C_2	fan rotor chord length
C_N	nozzle coefficient
C_V	sizing coefficient of valve [gal/min per psia$^{1/2}$]
D	diameter
$D(\theta)$	directivity factor of source
D_D	diameter of downstream piping
D_F	diameter of fan
D_i	inner diameter
D_j	jet diameter, fully expanded
D_N	nozzle diameter
D_o	outer diameter
D_P	pipe diameter
D_T	turbine diameter
D_U	upstream piping diameter
D_V	valve diameter
D_W	wire diameter
f_b	blade passage frequency
f_c	critical frequency (first mode cut-on) of pipe
F_D	valve style modifier
f_i	i-th pipe wall flexural resonance frequency
F_L	pressure recovery coefficient
f_p	peak frequency of noise emission
f_p'	peak frequency of noise emission
f_r	circular pipe ring frequency
G	specific gravity of gas
H	height of equipment
IL	insertion loss
K	pressure loss coefficient
L	length of equipment
L_P	sound pressure level
ΔL_P	differential sound pressure level
L_W	sound power level
L_{WS}	sound power level for structural fatigue
L_{WSN}	sound power level of silencer self-noise
M	Mach number of flow

$\dot{m}$	mass flow rate
$\%m$	percent moisture in steam
M_c	convection Mach number
M_j	jet Mach number
M_T	tip speed Mach number
M_{TR}	relative tip speed Mach number
M_{TRD}	relative tip speed Mach number, design
MW	molecular weight
N	rotational speed [sec^{-1}]
P_0	static pressure at vena contracta
P_1	static pressure upstream
P_2	static pressure downstream
P_A	ambient pressure
POA	percent open area [%]
PSE	peak static efficiency [%]
P_{TS}	total static pressure rise across fan
q	lobe number for rotor-stator interactions
Q	volume flow rate
r	distance to observation point
r'	effective distance from acoustic center of large equipment
R	gas constant
r_E	energy reflection coefficient
$R(f)$	room constant, frequency-dependent
RSS	rotor-stator spacing coefficient
S_1	inlet guide vane-fan spacing
S_2	rotor/stator spacing
S_A	area covered by sound-absorbing materials
SE	static efficiency [%]
S_R	area covered by sound-reflecting materials
t	blowdown time
ΔT	differential temperature
T_1	upstream temperature
T_2	downstream temperature
T_3	combustor inlet temperature
$T_{4,ref}$	combustor outlet/turbine inlet temperature, maximum takeoff power
$T_{5,ref}$	turbine outlet temperature, maximum takeoff power
T_a	ambient temperature
T_j	temperature of fully expanded jet
TL	transmission loss
ΔTL	differential transmission loss
T_s	superheat temperature
t_p	pipe wall thickness
u	velocity of local flow perturbation
U	centerline mean flow velocity
U_c	convection flow velocity
U_j	centerline mean flow velocity of jet, fully expanded
TL	transmission loss
V	blowdown volume
V_{TR}	tip velocity of last stage turbine rotor
W	width of equipment

W_A	acoustic power
W_M	mechanical power
Z	gas compressibility factor
α	sound absorption coefficient
β	shock parameter
δ	cutoff factor
Δ	differential spectral level
Δ_{shock}	differential spectral level, shock-associated noise
γ	ratio of specific heats
η	acoustic conversion efficiency
ρ	gas density
ρ_a	ambient gas density
ρ_e	expanded gas density
ρ_j	jet density, fully expanded
ρ_s	mass per unit area
ρ_W	density of water
σ	frequency-dependent shock parameter
ξ	adjusted pressure loss coefficient
ξ_1	reflection parameter
ξ_2	reflection parameter

B. DEFINITION OF NOISE CONTROL TERMS

A-weighting: An electronic filter system in a sound level meter that emphasizes frequencies most likely to cause hearing damage. Sound pressure level readings obtained using this weighting are referred to as "A-weighted sound pressure level" or simply "sound level" and are written with the abbreviation dB(A) or dBA and pronounced "dee-bee-ay".

acoustical lagging: noise control materials applied to the exterior of noise-radiating surfaces. Usually consist of a flexible layer of fibrous materials several inches thick covered with a massive jacket.

Baseline Criterion: As defined in the *Specifications Guide*, a criterion equipment noise emission level in dB(A) that applies to a *Group* of equipment without reference to siting or operational considerations.

blowdown: Relief of a fixed volume of high-pressure gas to atmosphere or a low-pressure tank from the atmosphere. Usually accompanied by high sound levels.

constrained jet: a high-velocity jet of air that is constrained within a pipe or other vessel. Control valves, orifices, venturis and intake vents all possess constrained jets.

conversion efficiency: efficiency of conversion of mechanical power to acoustical power. Typically increases with velocity and turbulence.

cut-on: condition for propagation of sound in a particular mode. Below the cut-on frequency, sound in the given mode attenuates rapidly with distance. Above the cut-on frequency, sound in the given mode propagates freely.

cutoff: a condition in which it is difficult for discrete tones generated in turbomachinery to propagate through the rotor-stator system to the environment.

decibel: dB- a measure of the amount of energy in an acoustic signal. A change of 10 dB indicates a 10-fold energy increase or decrease; a change of 20 dB corresponds to a 100-fold energy increase or decrease, etc.[v] The mathematical formulation of the dB is as the common logarithm of the ratio of the measured sound pressure to that of a signal that is barely audible. Thus, the decibel has no units, and strictly speaking is not a unit itself. However, it is common to state "the sound pressure level is 80 dB".

Design Guide: Reduced-Noise Gas Flow Design Guide.

diameter, fully developed jet: the diameter the jet has attained at a point where the axial core velocity begins to reduce with distance. Near the exit, the jet diameter increases as air is entrained. Usually several times the exit diameter.

[v] Because of the characteristics of human hearing, a ten-fold energy change corresponds to a two-fold change in perceived loudness; a one-hundred-fold energy change to a four-fold loudness perception change, etc.

dipole source: oscillatory force pair that radiates sound. Analogous to two closely spaced *monopole sources* operating out of phase. Typically associated with the interaction of flows and structures.

direct sound: sound that travels from its source to the observation point in a direct line, without striking reflecting obstacles or room surfaces.

dissipative silencer: a silencer that provides *insertion loss* by dissipating acoustic energy. Sound is converted into minute amounts of heat within the fibrous acoustic fill.

duct mode: A pressure pattern across the duct cross-section that propagates down the duct. Uniform pressure across the duct is called the plane-wave mode and propagates at all frequencies. More complex pressure patterns propagate only above their duct mode *cut-on* frequency.

far field: the sound field farther than a characteristic dimension from its source. Characterized by reduction in level with distance (in the absence of sound-reflecting obstacles).

flow noise: noise generated by fluid flow in the turbulent boundary layer of a pipe

free jet: a discharge of high velocity gas into the atmosphere, unconstrained by surrounding structures such as pipes.

Group Number: As defined in the *Specifications Guide*, a classification for equipment with similar noise emission expectations.

isentropic expansion/contraction: expansion or contraction of gas without the addition of entropy. A gas undergoes isentropic expansion or contraction when it is travels from one set of pressure/temperature/density conditions to another without encountering a shock.

Inlet Debris Screen: a screen placed over an air intake to prevent ingestion of debris, birds, etc.

in-line silencer: a silencer placed within the gas flow.

in-line sound power level: sound power level of gas within the flow, as opposed to radiating from the pipe walls.

Insertion Loss: IL, dB- in each octave band, the amount by which source levels are attenuated by the candidate noise control option. Insertion Loss data expressed in dB(A) should be carefully regarded, as the A-weighted level reduction for a given IL spectrum is a function of the original source spectrum.

intake vent: an opening to atmosphere for vacuum intake.

lagging: see *acoustical lagging*

MPSL: As defined in the *Specifications Guide*, the maximum permissible A-weighted Sound Pressure Level measured 1 meter away from the individual equipment item under consideration.

monopole source: an aerodynamic pulsation that emits sound.

near field: the sound field closer than a characteristic dimension from its source. Characterized by variable levels clustered around a more or less stable mean value.

pressure recovery: The degree of difference between the static pressure downstream and that in the vena contracta at a flow constriction. A pressure difference is accompanied by accelerated flow in the vena contracta relative to downstream velocities. Because acoustic *conversion efficiency* increases with velocity, large pressure differences (high recovery) may mean increased noise.

quadrupole source: a rotating (shear) force pair that radiates sound. Analogous to two closely-spaced dipole sources operating out of phase. Associated with turbulence.

reactive silencer: a silencer that provides *insertion loss* by presenting an acoustic impedance. Sound is reflected from the silencer.

Reflection Loss: dB – the numerical difference in sound power level approaching a pipe opening to that which is actually radiated. The remainder is reflected back into the piping system.

reverberant sound: sound that travels to the observation point via one or more room surfaces.

room constant (R): m^2 – an expression of the sound absorbing capacity of a room. Analogous to the area over which radiated sound power is distributed to give *reverberant sound.*

self-noise: flow noise generated by flow through a silencer.

sound-absorbing materials: materials or surfaces that remove sound energy from a given space. Most sound absorbing materials are lightweight and porous and remove sound energy by converting it to minute quantities of heat. A less obvious but powerful sound absorber is a large extent of open air: sound travelling out of open windows, missing walls and into the open sky does not return.

sound level: A-weighted sound pressure level

sound power: watt – the acoustic power associated with a source.

sound power level: L_W, dB – a decibel expression of the sound power. The reference sound power is 10^{-12} watts.

sound pressure: Pa –oscillatory pressure superimposed over static atmospheric pressure.

sound-pressure level: L_P, dB – a decibel expression of the sound pressure. The reference sound pressure is 2×10^{-5} Pa.

sound-reflecting materials: materials that do not remove sound energy but reflect it back into the space. Examples would be concrete block, plaster and the ground.

sound source: an equipment item or a part of an equipment item that emits audible noise.

source dimensions: the length, width and height of a rectangular box fitting over the sound source.

Specifications Guide: NASA Glenn Research Center "Guide to Specification of Equipment Noise Emission Levels"

Transmission Loss: TL, dB- in each octave band, the difference between the incident and transmitted sound power levels for the candidate noise control option. Similar to Insertion Loss, but in some cases introduction of the noise control option actually increases the sound power incident on itself. Transmission Loss data expressed in dB(A) should be carefully regarded, as the A-weighted level reduction for a given IL spectrum is a function of the original source spectrum.

vacuum vent: an opening to atmosphere for vacuum intake.

valve trim: a class of devices added within the body of a control valve to reduce noise emission by increasing the peak noise frequency and causing the pressure reduction to occur in smaller steps.

vena contracta: the point of smallest cross-sectional area downstream of a flow constriction.

wave divergence: the numerical difference between the sound power level of a source and the sound pressure recorded at a particular location, absent the effects of directivity. Represents the extent over which sound power must spread itself in a given environment. Because the magnitude of sound pressure power is dimensionally related to the sound power per unit area, spreading the sound power over a large area produces lower sound pressure levels.

C. DECIBEL MATHEMATICS

C.1. Energy Addition

The sound pressure level of a combination of sounds is computed on the assumption that the sounds are uncorrelated. This form of the equation is appropriate for use with calculators and computers.

$$L_{P,total} = 10\log_{10}\left(\sum_i 10^{0.1L_{P,i}}\right)$$

C.2. Energy Subtraction

Sound pressure levels can be subtracted as well. This might be done when attempting to subtract the influence of one machine from a reading on a group, or when attempting to remove the influence of ambient noise from a measurement.

$$L_{P,diff} = 10\log_{10}\left(10^{0.1L_{P,1}} - 10^{0.1L_{P,2}}\right)$$

This computation assumes that the sounds are uncorrelated. This form of the equation is appropriate for use with calculators and computers.

C.3. Mnemomic Method for Addition

A simplified method, accurate to approximately 1 dB, is well suited for spontaneous "in the head" calculations.

Decibel values are added two at a time. When adding a series of numbers, always begin with the lowest value and proceed to the highest. In each case, the sum of the two values will be the value of the greater of the two, plus a factor that depends on the difference between them.

$$L_{P,1+2} = L_{P,1} + \Delta\left(L_{P,1} - L_{P,2}\right)$$
where $L_{P,1} > L_{P,2}$

Δ	$L_{P,1} - L_{P,2}$
+3 dB	0 or 1 dB
+2 dB	2 or 3 dB
+1 dB	4 to 9 dB
+0 dB	10 dB or more

C.4. Calculation of A-weighted levels from octave bands.

A-weighted sound pressure levels or sound power levels may be computed to a reasonable accuracy from an octave band spectrum as follows:

$$L_{PA} = 10\log_{10}\sum_i 10^{0.1(L_{P,i}+A_i)}$$

where the values A_i for the octave bands are given in Table 21.

Table 21: A-weighting Corrections

Octave Band Center Frequency [Hz]	A-weighting Correction [dB]
31.5	-39.4
63	-26.2
125	-16.1
250	-8.6
500	-3.2
1000	+0.0
2000	+1.2
4000	+1.0
8000	-1.1